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THE PARALLEL INTERNAL-MASTER-OSCILLATOR POWER-AMPLIFIER FOR PHA--ETC(U)

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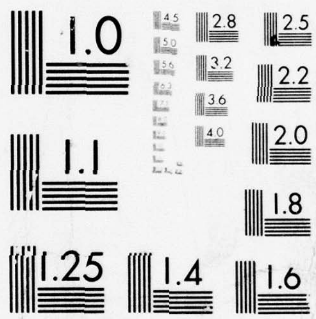

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REPORT SAMSO-TR-78-50

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The Parallel Internal-Master-Oscillator Power-Amplifier for Phase Matching the Output Beams of Multiline Lasers

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16 February 1978

Interim Report

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A conceptual device optics system is discussed, which, in principle, allows combining, on a large mirror, the multiline outputs of an arbitrary number of separate laser devices. In principle, each lasing transition from each laser will be in phase with the corresponding transition from the other laser devices that illuminate the other parts of the mirror. This will be true even if the multiline lasing transitions fluctuate rapidly (go on and off).

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20. ABSTRACT (Continued)

The concept involves the use of several equal size laser segments, possibly arranged in a polygon configuration for compactness. One segment is run as an oscillator; its output is split into a number of beams, which are used to drive the other laser segments as amplifiers. Because of the multiline nature of the laser mechanism, the basic requirement of the system is that the absolute lengths of the paths through the amplifiers from the oscillator output mirror to the large collecting mirror be equal.

In this report, the concept is developed in its simplest form; however, it should be compatible with both adaptive optics beam control (multisection movable mirrors) and techniques to correct beam steering caused by anomalous dispersion or by other effects.

SUMMARY

A conceptual device optics system is discussed, which, in principal, allows combining, on a large mirror, the multiline outputs of an arbitrary number of separate laser devices. In principle, each lasing transition from each laser will be in phase with the corresponding transition from the other laser devices that illuminate the other parts of the mirror. This will be true even if the multiline lasing transitions fluctuate rapidly (go on and cff). This concept has promise, for example, for very high-power HF chemical laser systems, where a single optical resonator would not be capable of extracting power from the laser medium with good beam quality, and as a backup for HF/DF cylindrical laser systems in case a practical annular resonator is not developed. In this report, the concept is developed in its simplest form; however, it should be compatible with both adaptive optics beam control (multisection movable mirrors) and techniques to correct beam steering caused by anomalous dispersion or by other effects. The following sections give (1) a discussion of multiline laser problems, (2) a description of the basic concept, and (3) the key issues that must be resolved before the concept's success is determined.

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FIGURES

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I. POTENTIAL PROBLEMS OF HIGH-POWER CW MULTILINE HF/DF LASERS

The CW HF (or DF) laser is attractive for many potential high-power applications because of its short wavelength, propagation, and efficiency characteristics. However, it is a low-density and, thus, a large-volume device, and it currently operates efficiently only on many simultaneous transitions (chemically related but optically independent), the order of 10. As a means of countering the volume problem, the cylindrical radial flow, annular gain region laser geometry has been proposed (it has other advantages also), and systems studies have indicated that such a device would be compatible with satisfactory platforms to the high-power levels of interest. However, large-scale annular resonators capable of extracting good quality beams at high efficiency have not yet been demonstrated, although a few small-scale laboratory studies have given encouraging results. Also, intuition should tell us that, even if such a device is successful at the moderate to large scale, the geometry requirements (annular width to laser nozzle bank diameter) for very high-power lasers will be such that a single annular resonator will not perform satisfactorily and may not be buildable. Therefore, it seems appropriate to investigate backup concepts for the cylindrical laser geometry that retain its compactness advantages and also offer the promise of good overall beam quality. The concept proposed here involves combining the output beams from several laser amplifiers, which are driven in parallel by a single oscillator.

The potential problems related to multiline operation are more subtle, if only because they depend on poorly understood physical phenomena. First, it has been observed in some devices that lasing can switch at high frequency between different VJ transitions and also between different modes under a single transition gain profile. If either of these happens in a single oscillator, it may be difficult, or impossible (depending on the frequency), to correct for

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phase fluctuations and distortions with a multisectional adaptive mirror. Second, anomalous dispersion causes the local index of refraction to vary away from line center across a gain profile. In a multiline laser with a simply configured resonator, if one line is controlled to be at line center, the other lasing lines cannot be there also. Thus, in principle, we can expect differential beam steering between the different frequency laser beams. Whether or not this will be important for interesting sized lasers is now under study. Simple estimates at Aerospace and somewhat more sophisticated estimates at UTRC* (but based on uncertain theory) show that, for a 2-MW size laser, the degradation effects on far-field beam intensity could amount to about 10% if the gain profiles were dominated by homogeneous broadening, or could be as large as several 100% if the gain profiles retained an inhomogeneously broadened nature. Obviously, it is important to resolve the physical principles involved here as well as to consider alternative resonator schemes in order to eliminate or reduce the effects to acceptable levels should they be found to be important.** The concept described here is adaptable to a scheme that, in principle, can correct for differential steering, and that should behave at least as well as a single smaller scale oscillator under line and frequency hopping conditions.

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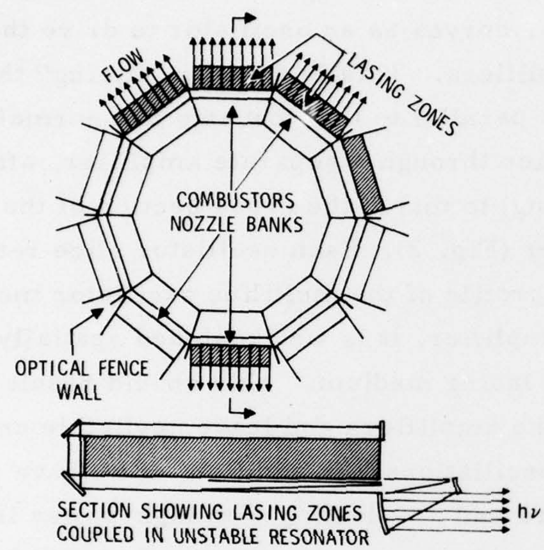
*United Technologies Research Corporation, East Hartford, Connecticut

**A negative branch unstable resonator can reduce considerably the steering effects of a multiline laser, but at the probable cost of significantly reduced power (because of absorption in parts of the resonator mode volume).

II. DESCRIPTION

Several nominally identical laser medium gain generators are arranged in a convenient geometry. One such configuration, the polygonal array shown in Fig. 1, retains the compactness feature of a single cylindrical laser. One generator, or possibly two in series, serves as an oscillator to drive the other generators as single-pass amplifiers. This is done by "slicing" the output of the oscillator (along planes parallel to the flow axis and normal to the optical axis) and passing each slice through a separate amplifier, after appropriate expansion (and hole filling) to match the cross section of the active lasing medium in the amplifier (Fig. 2). Each oscillator slice retains the upstream/downstream intensity profile of the multiline oscillator medium so that, when it is delivered to an amplifier, it is well matched spatially to the intensity profile of the amplifier lasing medium. This should result in efficient extraction of the power in the amplifiers and leave negligible unsaturated volumes to support parasitic oscillations. In addition, if we have a relatively small number of amplifiers and are dealing with high power levels, each amplifier will have a modest overall gain requirement and should be well saturated (see Appendix A).

Since the output of the device is only from the amplifier legs, and since the legs are each driven by the output of one oscillator, they should be in phase, line to line, with the same phase fronts that existed in the output beam from the oscillator leg. Moreover, if there is line or mode switching in the oscillator, the output beams will have the same characteristics; thus, at each instant of time, each lasing transition will be in phase with the corresponding transition emerging from the other amplifier legs. Therefore, the amplifier beams can be combined spatially on a large mirror (Fig. 3) by illuminating a separate part of the mirror with each amplifier, and the total beam can be transmitted to the far field as a large coherent source (as coherent as the oscillator beam, that is).



ADVANTAGES

1. COMPACT
2. MULTILINE AMPLIFIER OUTPUT BEAMS CAN BE PHASE MATCHED ON EACH LINE, IN PRINCIPLE, ON LATER MIRROR IN TRAIN
3. DEMONSTRATED OSCILLATOR OPTICS AT REASONABLE SCALE
4. INTENSITY MATCHING BETWEEN OSCILLATOR BEAMS AND AMPLIFIER MEDIA
5. OPERATES WITH MODE/TRANSITION HOPPING IN OSCILLATOR
6. REDUCES PARASITICS/MODE CONTROL LIMITATIONS
7. COMPATIBLE WITH MODE CONTROL AND ANOMALOUS DISPERSION STEERING CONTROL LINE SELECTION TECHNIQUES
8. ALLOWS SEGMENTED (opposite banks) DEVICE TESTING
9. "SIMPLE" THRUST CANCELLATION

REQUIREMENT

INTERNAL PARALLEL MOPA WITH ONE (OR PAIR OF) LASING ZONE AS OSCILLATOR. LENGTH EQUALIZATION REQUIRED FOR ALL AMPLIFIER PATHS.

Figure 1. Polygon Laser Configuration — Alternative to Cylindrical Configuration

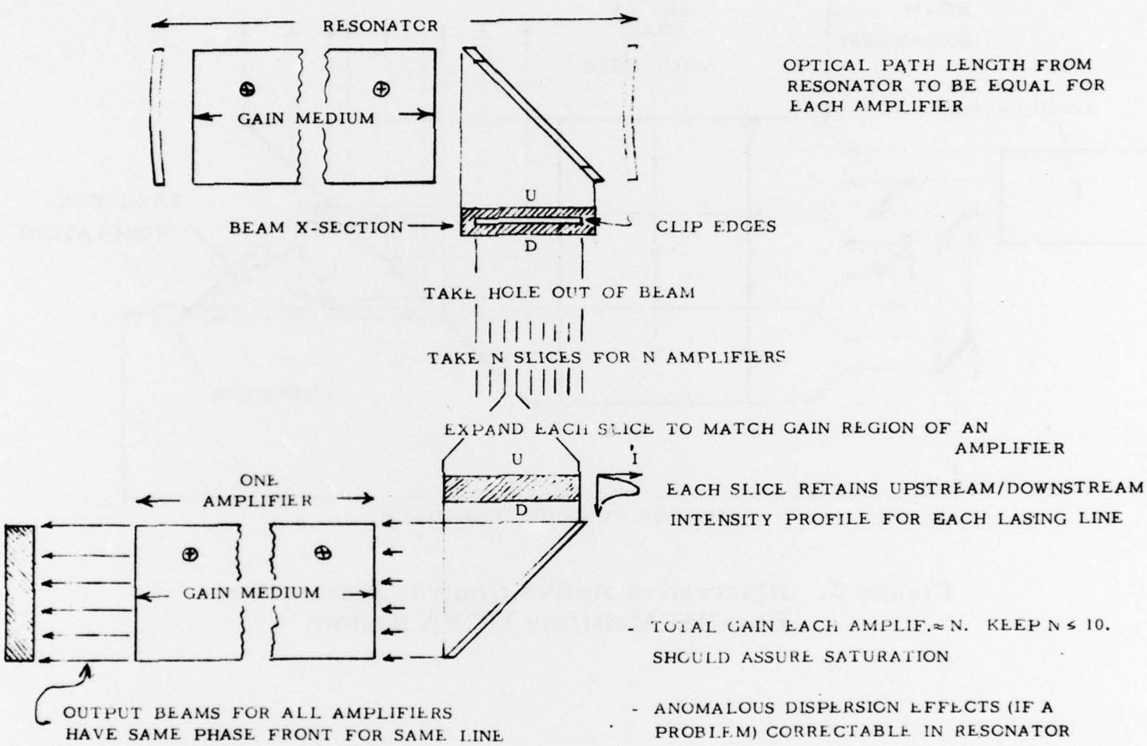


Figure 2. Internal Parallel MOPA for Multitiline Laser Device

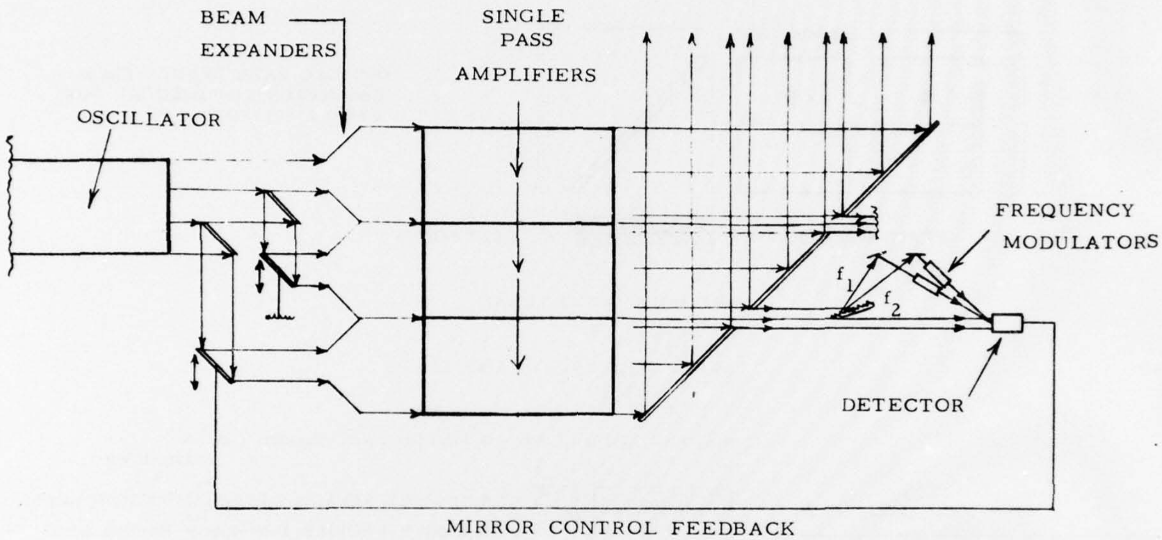


Figure 3. Illustrative Active Control System for Parallel Multiline MOPA System

III. KEY ISSUES AND APPROACHES TO THEIR RESOLUTION

There are several key issues associated with this concept. These issues and approaches to their resolution are discussed in this section.

A. ABSOLUTE LENGTH CONTROL

To assure that the phase of each laser transition is matched from all amplifiers at the large mirror, it is necessary to equalize absolute lengths from the oscillator exit to the collecting mirror through the amplifiers to within a small fraction of a wavelength (see Appendix B). This probably would be difficult to do with a nonadaptive mirror system. However, it may be practical to use a system of independently controlled mirrors, one for each amplifier, such as has been studied in adaptive optics applications.

A scheme that illustrates the principles involved is shown in Fig. 3. The output from each amplifier falls on a separate section of the mirror. There are small adjacent holes in the adjacent mirror sections through which the phase of two lasing lines are to be sensed. A dispersive element behind one hole is used to separate the two lasing frequencies.* These beams are then given different modulation frequency and are imposed on a beat frequency detector. The beam from the second hole is put directly onto the detector. This approach, the use of different frequency modulation of different chemical laser lines to allow the comparison of the phase of each line with the phase of the same line from another laser source, was suggested by Wang[1] in the description of an alternative scheme for the phase matching of several multiline laser oscillators. No attempt is made in Fig. 3 to show nominally equal

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*All lines are separated, of course, but only two are required for use in subsequent steps.

[1] C. P. Wang, Master and Slave Oscillator Array System for Very Large Multiline Lasers, ATR-77(8204)-2, The Aerospace Corporation, El Segundo, California (March 1977).

path lengths for the different optical paths (between the oscillator and mirrors and within the sensor), but this would be an essential requirement of a system design. The phase of one line is compared with the phase of the same line on an adjacent mirror surface, and one mirror in the train of one amplifier path is moved to eliminate any difference. The phase difference between the two mirror sections on the second line is then measured. If the two beams on the second line are not in phase, the relative position of the two mirrors is nominally changed by the integral number of wavelengths of the first line required to bring the beams on the second line into phase. This can be determined by measuring the original difference in phase for the second line when the first line is forced to be in phase. This follows from the simple analyses given in Appendix B. The same steps are then taken for the next adjacent mirror surfaces, and so on, until the phases on both lines are matched for all mirror surfaces and, therefore, for each amplifier segment of the device. Note that the key issue is to make the optical path lengths the same; thus, only two lines need to be sensed and phase matched (that is, all the others will be in phase when the lengths are matched). Once the equal length criterion is established, any line or frequency hopping in the oscillator will not destroy the phase-matched property of each line across the face of the large mirror. The key requirements here are the development and demonstration of the phase sensing diagnostics and of the mirror control system. For such an experimental study, the amplifier components are not needed. One laboratory scale laser with good multiline beam quality would be used. Its output beam would be divided into two beams that would be transmitted along nominally equal path lengths to the two parts of a mirror where the sensing and control functions are accomplished. The performance of the system could be evaluated interferometrically by use of the beams that reflect from the fronts of the different mirror sections. The optical path lengths could be varied dynamically as well as statically in order to determine the response of the system.

This discussion is intended to illustrate the concept and suggest that there are "in principle" methods for approaching separate path length equalization. Undoubtedly, there are other approaches to this requirement. For example, another concept is one in which the multiline beams falling on adjacent mirrors are filtered to pass only one line from each beam into an interferometer. When the phase-matching requirement is achieved for that line, the filter is replaced by one that passes only another line, and the phase-matching control function is repeated. When both lines are in phase, length equalization has been achieved. Perhaps the most practical approach proposed to date uses the principles of white light interferometry as suggested by Turner.*

B. SATURATION

As pointed out earlier and in Appendix A, the entrance power flux into each amplifier can be fairly high and can vary over a wide range of values depending on the design characteristics of the device (power level, length and height of each nozzle bank, and number of amplifiers). At this time, however, it is not clear what line-by-line flux level is required for adequate amplifier saturation, and confident design limits for the concept cannot be made. A study is required that accurately matches the input intensity profiles expected from an oscillator with the gain medium of each amplifier. Previous laboratory results with single (or a few) lines that interact with only a small volume of the amplifier gain region are not adequate, since they are difficult to interpret and impossible to scale to the real case. It is difficult to perform such a study experimentally, since it probably requires two fairly large chemical laser devices. However, the application of one or more of the theoretical techniques now available should be sufficient to evaluate the phenomena quantitatively and, also, to study the effects of parametric variations. Then, a single experimental demonstration with a pair of large devices could be used to validate or at least "anchor" the theoretical predictions.

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*E. B. Turner, private communication.

C. PRACTICAL OPTICAL TRAIN

As noted above, the success of this concept depends on equal optical paths between the oscillator output mirror and the large mirror. In addition, if we assume that the oscillator has an edge-coupled unstable resonator, the optical train must remove the "hole" from the beam (probably best done before slicing the beam for each amplifier). In principle, this can be done with the use of straightforward geometric optics design. However, since we want to achieve a compactness advantage for the entire system, the requirements of the optical train must not be allowed to dictate an awkward device geometry. Therefore, a design study should be made to establish practical oscillator/amplifier/optical train configurations for this concept.

D. MODE SWITCHING/HOPPING AND ACTIVE FREQUENCY CONTROL

Unstable phenomena, which have been observed in some laser devices, are not well understood and, as mentioned earlier, could limit the effectiveness of multisurface mirror adaptive control of a multiline chemical laser beam. In general, this is also true for the parallel internal MOPA concept; however, this approach may have one practical advantage. The concept allows consideration of a high-power laser device that is driven by an oscillator stage of the order of 1/10 the total power (actually, one over the number of amplifiers used in a given design); in principle, the amplifier legs are each forced to produce a beam with the phase, unsteadiness, and nonuniform characteristics of the oscillator beam. If it happens that a serious problem occurs in beam control because of rapid longitudinal mode hopping across single transition gain profiles, the relatively small size of the oscillator may provide an advantage. That is, it may be possible to control a single oscillator to run on only one longitudinal mode for each VJ transition. Intuitively, we expect this to be more feasible for a short oscillator than for a long one, since the allowed longitudinal modes will be spaced further apart. This single longitudinal mode control idea is a feature and requirement of the multiline laser phase-matching concept proposed by Wang,[1] but it also appears to have merit for the parallel MOPA concept. The scheme proposed by Wang to actively control several VJ transitions simultaneously in the oscillator is based on the off-Littrow-angle-multiple-selected-line technique demonstrated by Chodzko.[2] Added to this is an active feedback system that senses the frequency of each VJ transition and rapidly moves each small resonator mirror to keep the frequency at a constant value.

It is conceivable that in an ideally supported laser system, a preset selected line resonator would have a stability adequate for single-mode operation; however, in a practical vibrating system, it is likely that an active control feature will be required.

E. ANOMALOUS DISPERSION BEAM STEERING

Should this phenomenon prove to be important, it should be correctable by forcing the oscillator medium to lase near line center on each VJ transition through use of the multiple selected line technique.[2]

Again, with a preset optical system, it might be possible to obtain adequate frequency control to reduce beam degradation due to this phenomenon to an acceptable level; however, the actively controlled modification discussed above also could be used here for finer frequency control if necessary.

F. EFFECTS OF MEDIUM PROPERTY DIFFERENCES IN THE AMPLIFIERS

If the medium properties vary for different amplifier paths such that there are differences in the total index of refraction for these paths, we can expect some loss in our ability to achieve the essential requirement for this system of path-length equalization. However, this effect should be small even for very large laser devices. For example, for nominal amplifier path lengths of 5 m, a helium environment along the optical paths at 40 Torr and

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[2] R. A. Chodzko, "Multiple Selected Line Unstable Resonator," Appl. Opt. 13, 2321 (1974).

0°C, a $\Delta\rho/\rho$ difference between paths of 5%, and two laser transitions corresponding to λ - 2.9 and 2.6 μm, a simple analysis gives an uncorrectable phase difference for each line on two adjacent mirror sections of about 4°. It should be possible to duplicate the laser and path media for each amplifier leg to at least a 5% density tolerance.

APPENDIX A. SIMPLIFIED EXAMPLE OF SATURATION REQUIREMENTS

Consider an 11-element HF chemical laser configuration with equal active medium dimensions for each element. One element serves as the oscillator for the other 10 elements, which serve as single-pass amplifiers.

Assume

1. 10×200-in. nozzle bank flow area
2. 2-in.-long laser zone in flow direction
3. 1 kW/in^2 of nozzle bank area, or 2 MW/element

Therefore

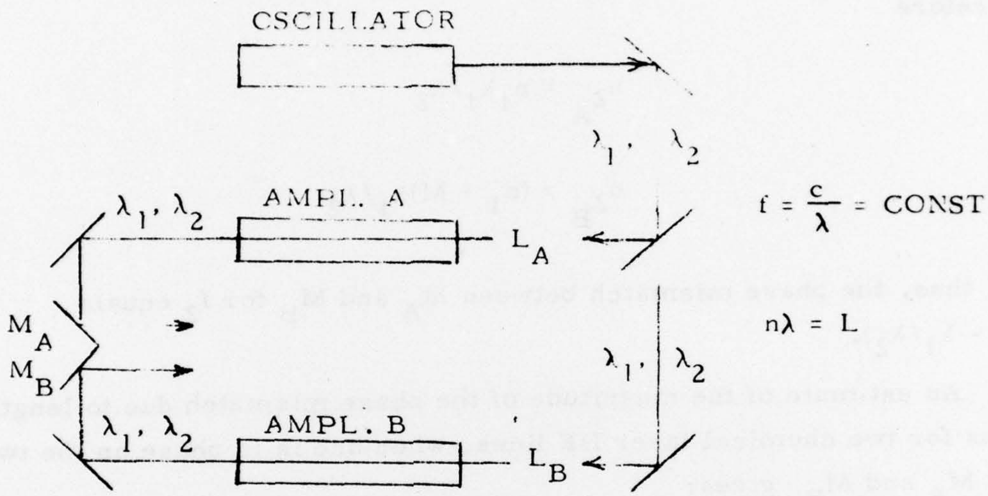
1. 10 slices of oscillator output beam give 200 kW as the input power to each amplifier. Thus, a modest overall gain of 11 is required for each amplifier.
2. Average input intensity to each amplifier = 200 kW/20 in^2 = 10 kW/in^2 = 1.6 kW/cm^2

Conclusions

1. The 1.6 kW/cm^2 should be enough to saturate each amplifier medium reasonably well, particularly with the intensity-matching characteristic inherent to this concept. Therefore, a laser power of <u>22 MW</u> results from this example.
2. However, if the saturation requirement is greater than 1.6 kW/cm^2, we can consider an example of a <u>five-sided polygon</u> configuration composed of 2-MW segments. In this case, our saturation flux will be <u>3.9 kW/cm^2</u>, and the total device laser beam power will be <u>10 MW</u>.
3. Clearly, the saturation requirements for a CW HF laser amplifier will have to be better understood for eventual systems designs. The purpose here is to illustrate simply that significant saturation fluxes and significant power levels apparently are achievable with this concept.

APPENDIX B. EFFECT OF VARIABLE LENGTH ON PHASE OF PARALLEL MULTILINE/MOPA OUTPUT BEAM

Problem: If length from oscillator output through different amplifiers varies, how badly is phase mismatched? Length of interest is to the first collecting mirror downstream of the amplifier exits at which adaptive corrections can be made if necessary.



L_A, L_B are lengths between oscillator output mirror O and mirrors M_A, M_B through amplifiers A, B.

Assume that M_A, M_B are adjusted so that f_1 is phase matched on M_A and M_B, but $L_A \neq L_B$ by an integral multiple of λ_1, M.

Therefore

$$L_A = n_1 \lambda_1$$

$$L_B = (n_1 + M)\lambda_1$$

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For f_2

$$L_A = n_{2_A} \lambda_2 = n_1 \lambda_1$$

$$L_B = n_{2_B} \lambda_2 = (n_1 + M)\lambda_1$$

Therefore

$$n_{2_A} = n_1 \lambda_1 / \lambda_2$$

$$n_{2_B} = (n_1 + M)\lambda_1 / \lambda_2$$

and, thus, the phase mismatch between M_A and M_B for f_2 equals $M(1 - \lambda_1/\lambda_2)$.

An estimate of the magnitude of the phase mismatch due to length variations for two chemical laser HF lines, when one is in phase on the two mirrors M_A and M_B, gives:

Assume

$$\lambda_1 = 2.6\ \mu m,\ \lambda_2 = 2.8\ \mu m$$

For

$M = 0,\ L_B = L_A,\ \lambda_2$ phase mismatch $= 0$

$M = 1,\ L_B = L_A + \lambda_1 \qquad = 0.07 = 26°$

$M = 2,\ L_B = L_A + 2\lambda_1 \qquad = 0.14 = 52°$

Therefore, it is important to maintain the lengths L_A and L_B nominally equal to each other.

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